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RIPENING OF PEARS AND APPLES AS MODIFIED BY EXTREME TEMPERATURES

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This work was undertaken as the result of an article by SHAMEL (8), in which he stated that a box of hard ripe Bartlett pears were placed in a lemon storage room where the temperature ranged from 79 to 100° F., with an average of 83.5°, the relative humidity varying from 85 to 96 per cent, with an average relative humidity of 85.1 per cent. The pears were subjected to these conditions from August 4 to September 3, 1916. Even though surrounded by these comparatively high temperatures, the pears remained hard and green until the end of the experiment (a period of 30 days). Within 6 or 7 days after being removed the pears ripened normally and were excellent to eat. As a check, SHAMEL compared these pears with other lots which had been stored in a room of a dwelling, where no attempt was made to control the temperature or relative humidity, but where one would assume both these factors would be lower than in the lemon house. Pears from this family storage room were ripe within a week, by August 10.

SHAMEL states that the "condition of high relative humidity was a controlling factor in retarding the ripening of the pears." He further states that "it is almost unbelievable that pears can be held for 30 days at the high temperatures recorded, without ripening or deteriorating." SHAMEL'S observations seem startling when considered wholly from the viewpoint of experience in the

employment of cold storage and the utilization of low temperatures for the purpose of delaying the ripening of fruit. On the other hand, they seem to be in accord with certain observations which indicate that high temperatures, as well as low, may tend to retard the ripening process of fruit. In this connection the following observations of the writers are of interest.

When certain varieties of plums and cherries, early in their development upon the trees, are inclosed in closely woven, black sateen cloth sacks, there is a delay of 4 or 5 days in the attainment of maturity, and a prolonging of the period of edibility from 5 to 8 weeks after the crop of exposed fruits is normally harvested and eaten (7). At the time these data were presented, it was believed that light exclusion was the responsible factor; but in view of SHAMEL'S observations, it might have been high temperatures and high relative humidity in the area surrounding the fruits as a result of the covering of black sacks, the black cloth absorbing the heat rays and lessening the loss of moisture from the fruit. At least it is possible that the activity of the enzymes bringing about ripening was checked or partially inhibited.

BIOLETTI (3) has noted that European varieties of *Vitis vinifera* L. do not ripen in parts of California precisely according to the theory of ANGOT (1), who states that the buds of the European grapevine commence activity when the mean daily temperature reaches 9° C. From this point until the ripening of the grapes, the sum of the mean daily temperatures above 9° C. must reach 1130° C. for the earliest varieties, and 1520° C. for the latest. BIOLETTI finds that under Californian conditions the actual dates of ripening are from 2 to 4 weeks later than the time estimated by ANGOT, and that the greater delays in ripening are in the hotter localities. For example, in the Coachella Valley the seasonal sum of temperature above 9° C. from February to November is 5728° F. Accordingly, the grapes should ripen there from May 3 to May 23. As a matter of fact, the earliest varieties ripen about May 15–30, and the latest about June 15–30. BIOLETTI thinks that in these hottest regions the temperature of maximum acceleration may be passed, and intimates that the temperatures may become so high that a retarding effect upon the ripening is exerted.

Pears in the Vaca Valley, near Vacaville, California, have behaved in a way to indicate that high temperature may retard ripening. Although the Vaca Valley is famous for its early fruits, especially cherries and apricots, it is a well established fact that Bartlett pears grown there are notably longer in reaching maturity than those from any other section of northern California, unless it be from the mountain sections where the seasons are very late in opening, owing to their high elevation. One of the writers[1] has often seen a full crop of immature Bartlett pears still hanging on the trees in this valley when practically the entire crop was gone from orchards in both coast and interior valley sections. In the spring the pear trees blossom comparatively early, as do the other fruits. The young pears develop normally until the hot summer weather predominates, when they apparently almost cease growth, or at least grow slowly until cooler fall weather comes. Then the pears seem to commence growth again, often increasing noticeably in size and ripening in the normal way. It should be noted, however, that while the summer temperatures in Vaca Valley are generally unusually high, the relative humidity is practically always comparatively low.

In discussing SHAMEL'S interesting results and the results obtained by the writers, later recorded in this paper, WHITTEN, of the Division of Pomology, University of California, recalls observations which apparently bear upon this subject. He comments as follows:

> During the summer of 1901 there prevailed in the Mississippi valley the most severe drought and the highest temperatures recorded for that section since the United States Weather Bureau was established. During that season pears remained firm on the trees much later than in normal years. In numerous instances varieties were exhibited at fall and winter fruit shows in Missouri, weeks later than the same varieties ordinarily keep for exhibition. Similar retardation, but to a less degree, of the development of pears, in the same section, has been observed to occur during occasional subsequent dry, hot summers.
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> The casual explanation, usually offered at that time, was that the development of the pears was retarded by unfavorable conditions for growth, and that

[1] Observations made in Vaca Valley during the growing seasons since 1912 by TAYLOR.

this retarded development resulted in later ripening. The results of investigations initiated by SHAMEL seem to justify the further interpretation that tardy ripening during unusually hot summers may have been due to the high temperatures opposing the ripening process.

Clusters of grapes, included in sacks during their growing period, ripen later and keep decidedly longer than do similar grapes not protected by sacks. Their longer keeping has been regarded as being due to protection afforded by the sacks from injurious agencies. It is now possible to assume, however, that the higher temperature within the sack may account, in part at least, for both later ripening and longer keeping qualities.

CARDINAL TEMPERATURES.—As is well known, certain cardinal or fundamental temperatures are recognized. "Maximum" and

TABLE I

PLANT	MINIMUM	OPTIMUM	MAXIMUM
	Cardinal temperatures for growth, ° C.		
Corn	4.8–10.5	37–44	44–50
Pea	0.0– 4.8	25–31	31–37
Cucumber	15.6–18.5	31–37	44–50
Wheat	0.0– 4.8	25–31	31–37
Barley	0.0– 4.8	25–31	31–37
	Cardinal temperatures for germination, ° C.		
Corn	9.4	34.0	46.2
Pea	9.4	34.0	46.2
Cucumber	14.0	34.0	46.2
Wheat	5.0	29.0	42.0
Barley	5.0	29.0	37.5

"minimum" are terms used to refer to the highest and lowest temperatures at which the development of a particular organism may occur. The most favorable temperature for any process or function is designated the "optimum." The optimum temperatures as a rule do not have a wide range. A variation of 5 or 6° one way or the other may be sufficient to have an appreciable effect upon the process or function involved. Furthermore, it is known that there may be separate maxima and minima for every process or activity or tissue of the plant. As shown in table I, HABERLANDT (6) gives a comparison of the relation of the different activities of a few plants to these cardinal temperatures. These figures are only suggestive, because the particular variety of the

same species and the other environmental factors would affect the cardinal temperatures.

It would not necessarily follow that the best temperature for the greatest vegetative growth of pears, for example, would likewise be the most favorable for fruit development, and this is generally recognized by growers. Furthermore, the most favorable temperature for the growth of the fruit on the tree may not be the optimum for continued ripening of the fruit after harvesting, with best flavor and resulting texture.

INHIBITION AT HIGH TEMPERATURES.—The fact is well known that metabolism, enzyme action, and other processes or functions of the plant are to a certain point rapidly increased with a rise in temperature. BLACKMAN (4), however, has shown that the maximum activity, especially for respiration and photosynthesis, has commonly been placed too high, since proper consideration of the time factor has not always been given. Above a certain point it has also been clearly shown that high temperatures weaken and lessen general metabolic activities.

From work done by BALLS (2) it is possible that the inhibition of growth at high temperatures during a considerable period of time may be the result of an accumulation in the cells of injurious metabolic products. BALLS thinks that some of these deleterious products are produced at low temperatures, but under such conditions they are decomposed about as rapidly as formed. At high temperatures, however, production is more rapid than decomposition, and accumulation takes place which results in the injury or inhibition of metabolism.

GORE (5), using temperatures from 2° to 35.6° C., found the rate of respiration increased an average of 2.376 times for each 10° C. rise in temperature for 49 sets of determinations, with 40 different kinds of fruits. An interesting statement by GORE is that "with many fruits the activity has been found to decline when held at high temperatures."

Experiment 1

In view of SHAMEL'S report and the degree to which it seemed to be substantiated by minor similar experiments and observations

of the writers, it was decided to conduct the following preliminary experiments. While SHAMEL believed it was the high relative humidity which was the controlling factor in retarding the ripening of the pears, nevertheless the factor of high temperatures was also present. Hence an experiment was outlined to endeavor to determine whether high temperatures, or humidity, or both were responsible.

METHOD

To obtain for the test what appeared to be the more important combinations of temperature and humidity, compartments were arranged as follows: (1) To maintain high temperature and high humidity a large drying oven, having a ventilation outlet at the top, was arranged with four shelves above two electric heaters. Between the heaters and the shelves were buckets of water with sacks and towels hanging into them to increase the evaporating surface. (2) For high temperature and low humidity a Freas electric oven was used with sufficient ventilation to maintain a comparatively low relative humidity, but sufficient heat to maintain a comparatively high temperature. (3) Two lockers were maintained at room temperature, one with ordinary humidity of the room and the other with provision for maintaining a high relative humidity. (4) The cold storage room where a check lot of pears was kept, was maintained constant by means of a thermostat, so that the temperature was always between 30.5° F. and 32.8° F., with the relative humidity ranging from 67 and 73 per cent. Throughout the experiment, which continued for 21 days, one hygrothermograph was kept on the third shelf (next to the bottom shelf) in the large drying oven, and another in the locker with normal temperature and high humidity. These were both checked several times by wet and dry bulb psychrometer and tested mercurial thermometers.

Eight 5 lb. grape baskets were filled with Bartlett pears and placed at noon on September 2 in the various situations. Each lot was numbered and described as follows:

Lot 1, top shelf (no. 1) of large oven; high temperature 85° F. and high humidity 100 per cent.

Lot 2, next to top shelf (no. 2) of large oven; high temperature 88° F. and high humidity 100 per cent.
Lot 3, next to bottom shelf (no. 3) of large oven; high temperature 94° F. and high humidity 91 per cent.
Lot 4, bottom shelf (no. 4) of large oven; high temperature 104° F. and moderate humidity about 60 per cent.
Lot 5, in small Freas electric oven; high temperature 95° F. and low humidity well below 50 per cent.
Lot 6, ordinary locker in concrete building; room temperature 71° F. and room humidity about 60 per cent.
Lot 7, ordinary locker in concrete building; room temperature 69° F. and high humidity 92 per cent.
Lot 8, held in cold storage at between 30.5° and 32.8° F. and a humidity ranging from 67 to 73 per cent.

Observations on temperature and humidity

In addition to the continous hygrothermograph records made by lots 3 and 7, the writers made careful check readings on thermometers at intervals of 1 to 4 days apart. For reference, these are given in table II.

TABLE II

Temperature records during storage tests

Date	Time	Temperature of lots in °F.							
		1	2	3	4	5	6	7	8†
September 2...	11:10 A.M.	85.5	89.5	94.0	106.0	.....	.....	.....	31.3
3...	3:00 P.M.	84.0	89.0	92.0	104.0	86.0	70.7	70.0	31.0
6...	9:45 A.M.	83.2	89.0	95.2	107.6	87.0	69.2	68.0	32.8
7...	9:00 A.M.	84.5	90.0	95.7	107.0	.....	.....	68.5	31.4
9...	12:15 P.M.	88.5	90.0	98.0	112.1	.....	69.2	67.5	30.5
10...	3:45 P.M.	84.5	90.0	95.7	107.6	96.8	70.0	68.0	32.7
14...	12:00 Noon	84.0	87.0	92.2	100.8	97.7	72.7	70.2	31.4
16...	12:15 P.M.	.....	85.5	93.0	102.2	96.8	71.0	69.0	31.7
19...	1:45 P.M.	.....	86.0	93.2	103.1	93.6	72.0	69.5	32.4
20...	11:45 A.M.	.....	.....	84.0	86.5	94.1	.....	.....	32.8
20...	5:40 P.M.*	.....	.....	77.0	77.0	.....	.....	.....	.....
21...	11:45 A.M.	.....	.....	92.0	96.1	101.3	.....	.....	30.8
23...	9:45 A.M.	.....	.....	100.5	107.2	103.1	.....	.....	30.7
Average..	.....	84.9	87.7	93.9	103.7	95.0	70.7	68.9	31.7
Maximum.	.....	88.5	90.0	100.5	112.1	103.1	72.7	70.2	32.8
Minimum.	.....	83.2	85.5	77.0	77.0	86.0	69.2	67.5	30.5

* Electric current off from 11:45 A.M. to 5:40 P.M. only.

† Temperature with lot 8 in cold storage remained quite uniform, rising to the maximum and dropping to the minimum with each run of the compressor about every 3 hours.

The records were made immediately on first opening the doors to the ovens or other compartments, two observers working together. During the time observations were being made, the temperatures as well as the humidity dropped, but the hygrothermograph charts show that under the high temperatures prevailing in the large oven, normal conditions were restored in 30 minutes to 2 hours as regards temperature, and in 1 to 2 hours as regards humidity. In the locker with lot 7, with air temperature normal,

TABLE III

HUMIDITY RECORDS DURING STORAGE TESTS

Date	Time	Percentage of relative humidity of lots				
		1	2	3	7	8*
September 2...	11:10 A.M.	100	100	92.0	.....	69.0
3...	3:00 P.M.	100	100	.....	82.0	68.0
6...	9:45 A.M.	100	100	89.0	84.0	73.0
7...	9:00 A.M.	100	100	88.0	92.0	69.0
9...	12:15 P.M.	100	100	82.5	96.0	67.0
10...	3:45 P.M.	100	100	83.0	91.0	73.0
14...	12:00 Noon	100	100	94.0	96.0	69.0
16...	12:15 P.M.	.....	100	93.0	98.0	70.0
19...	1:45 P.M.	.....	100	89.0	97.0	72.0
20...	11:45 A.M.	.....	.....	100.0	.....	73.0
21...	11:45 A.M.	.....	.....	98.0	.....	68.0
23...	9:45 A.M.	.....	.....	93.0	.....	68.0
Average....	.....	100	100	90.7	91.7	70.0
Maximum..	.....	100	100	100.0	98.0	73.0
Minimum...	.....	100	100	82.5	82.0	67.0

* Humidity with lot 8 in cold storage remained quite uniform, rising to the maximum and dropping to the minimum with each run of the compressor about every 3 hours.

high humidity was restored in 4 to 10 hours after closing the door. In no case, however, did the humidity drop below 90 per cent and remain there for more than one hour. The slow rise from 95 to 100 per cent, or to saturation, required the longest time.

The observations on humidity are shown in table III. Lot 4 ranged about 60 per cent humidity; lot 5 ranged well below 50 per cent; and lot 6 ranged from 53 to 65 per cent humidity. Lots 1 and 2 are indicated as having always been in a saturated atmosphere. This was assumed from the fact that every time the door was opened to take readings, the walls, top, and bottom of

the shelves were covered with drops of precipitated moisture, and the wrapping paper surrounding the fruits was always moist. This was not generally true with lots 3 and 4. The condition of the fruit itself, as indicated by its wilting, should serve as a good indication of the relative humidity of the atmosphere surrounding the various lots. This will appear later.

Behavior of fruit

In the beginning of the experiment all the pears were very similar in degree of ripeness, all being yellowish green and about one-fourth ripe, as indicated by color. Degree of ripeness may be described from two standpoints, namely, appearance, indicated largely by color, and condition, indicated by texture, juiciness, and flavor. It was possible to describe the former as a certain fraction ripe, and the fractions in table IV refer to ripeness in appearance only, unless otherwise noted. Additional statements cover condition. The pears in each lot were examined at approximately 4-day intervals, and careful notes made as to appearance and condition. The somewhat abridged notes in table IV indicate the condition of the fruit as the experiment progressed.

The experiment was continued beyond September 23, but on the 25th an accident in the regulation caused the temperatures to climb abnormally high in the box where nos. 1–4 were located. The result was that the pears in lots 3 and 4 were cooked brown, so that further observations were impossible. It was interesting to note, however, that lot 3 was cooked much more severely than lot 4. The temperature of lot 3 as compared with lot 4 was approximately 10° lower, while the relative humidity was about 30 per cent higher. Just before this, one fruit each from lots 3 and 4 were placed where lot 7 had been at room temperature and high humidity, to discover whether these fruits would ripen normally after removal from the high temperature. These fruits were observed and sampled on September 28. No. 3, although noticeably wilted on September 23, had by the 28th become apparently more plump, appearing almost normal. The fruit was full soft ripe; flesh rather tough; and flavor more acid than normal, with a faint trace of bitterness, although this may have been due

TABLE IV

CONDITION OF PEARS DURING PROGRESS OF STORAGE TEST

LOT NO.	TREATMENT	DATE OF EXAMINATION				
		September 6	September 10	September 14	September 19	September 23
1.....	High temperature (85° F.), high humidity (100 per cent)	Three-fourths ripe, greenish yellow to yellow, all in good condition, plump	Full ripe, clear yellow, medium firm ripe condition, few small breakdown spots on surface	Past ripe, soft, considerable breakdown and decay developing*	.....	.....
2.....	High temperature (88° F.), high humidity (100 per cent)	Two-thirds ripe, greenish yellow, all in good condition, plump	Four-fifths ripe, plump, firm, unripe	Nine-tenths ripe, full yellow, firm ripe, few fruits showing small decay spots	60 per cent breakdown and mold, rotten*	.....
3.....	High temperature (94° F.), high humidity (91 per cent)	One-half ripe, yellowish green to greenish yellow, all in good condition, plump	Two-thirds ripe, greenish yellow, hard, unripe, faint trace of wilting	Three-fourths ripe in color and texture, some fruits plump, others very slightly wilted	Nine-tenths ripe in appearance, nearly to full yellow, four-fifths ripe in texture, hard or very firm ripe, slightly wilted	Fully colored yellow, firm, unripe, wilted
4.....	High temperature (104° F.), moderate humidity (estimated 60 per cent)	One-third ripe, yellowish green, one pear rotten, others good, plump	One-half ripe, yellowish green to greenish yellow, perceptibly wilted, one with complete breakdown in lower one-third of length	One-half ripe, practically the same as on September 10	Two-thirds ripe, greenish yellow, two-thirds ripe in texture	Three-fourths to four-fifths colored yellow, hard unripe, rather badly shriveled, dry

5.....	High temperature (95° F.), low humidity (less than 50 per cent)	Five-sixths ripe, yellow, wilting slightly	Thermostat out of adjustment, temperature too high, fruit cooked; new lot from storage to replace old	One-half ripe (almost), nearly as ripe as lot 4	Two-thirds ripe, same as lot 4	Three-fourths to four-fifths colored yellow, same as lot 4 in every way
6.....	Room temperature (71° F.), room humidity (60 per cent)	Nine-tenths ripe, nearly full yellow, firm ripe, plump	Almost as ripe as lot 1	Full ripe to past ripe, or medium to soft ripe, undisturbed fruits in best condition	Dead ripe to past, all fruits show more or less breakdown*	.....
7.....	Room temperature (69° F.), high humidity (92 per cent)	Five-sixths ripe, yellow, plump, good condition	Practically as ripe as lot 1	Full ripe to slightly past, no noticeable difference as compared with lot 6	Same as lot 6*	.....
8.....	Cold storage (32° F.), moderate humidity (70 per cent)	One-fourth ripe or less	Remained practically the same throughout period of experiment.			

* Removed from the experiment.

to the absorption of the odor from the cedar wood closets in which the fruit was held. At any rate, the ripe fruit was much poorer in quality than the Bartlett at its best when ripened at normal temperatures. No. 4 was still as wilted as before. Fruit was full ripe, but dry and tough. This fruit remained about as wilted as when first placed. The fruit was not soft, but as much so as it ever would be without being well past ripe. It was very inferior in flavor and quality, much the same as no. 3. Lot 8, which was held in cold storage throughout the progress of the experiment, showed almost no appreciable ripening, being practically as hard and unripe at the end of the month as at the beginning.

Discussion of results

The pears in lot 1, placed at a temperature averaging about 85° F. and in a saturated humidity, were full ripe 8 days after being subjected to the conditions. A study of table IV shows that the pears in lot 2, placed at a temperature averaging 87.7° F. and in a saturated atmosphere, were full ripe about 13 days after being subjected to the conditions. Since the fruit was all in the same stage of maturity before the experiment started, this would show a delay of 5 days in ripening, which can only be accounted for by the fact that the temperature was about 3° higher.

The pears in lots 6 and 7 were also full ripe 8 days after the experiment started. The temperature surrounding lots 6 and 7 was practically the same in both cases, and averaged about 70° F. The difference in the conditions surrounding these two lots was in the humidity. The humidity in the compartment containing lot 6 was fairly constant, about 60 per cent; the humidity surrounding lot 7 averaged about 92 per cent. The temperatures alike, the difference in humidity showed no effect upon the ripening. Furthermore, when compared with lot 1, the fruit ripened with approximately the same rapidity at temperatures of 70 and 85° F. The pears in lot 3 remained firm unripe for 3 weeks after being subjected to a temperature averaging about 94° F. and a humidity of 91 per cent. This shows a delay of 13 days when compared with lots 1, 6, and 7. This apparently was due to the somewhat

greater temperature at which the pears were kept. The somewhat lower humidity resulted in the pears wilting appreciably. The pears in lot 4 were hard unripe, or not quite as ripe as the fruit in lot 3. The temperature averaged about 104°F. and the humidity approximately 60 per cent. The higher temperature resulted in an appreciable delay in ripening when contrasted with lot 3, but the lower relative humidity caused considerable wilting. With the high temperatures some difficulty was experienced in maintaining as high humidity as was desired in the case of lots 3 and 4.

Interpretation of results

It is somewhat difficult to account for the surprising results obtained. The general idea has been that low temperatures only were of importance in preserving fruits for any period of time and in arresting the deteriorating processes. As contrasted with this, high temperatures were looked upon as extremely conducive to a hastening of the breakdown of the tissues and in shortening the keeping period of fruit.

The delay in ripening might be assumed upon the basis of an accumulation of carbon dioxide, the assumption being that possibly a comparatively large mass of fruit stored in a relatively small closed container, at high temperatures, would result in an abnormal amount of carbon dioxide surrounding the fruit. The writers, however, doubt whether there was any measurable accumulation of carbon dioxide, since the capacity of the drying oven was relatively large for the amount of fruit contained therein. Furthermore, the ventilation pipe at the top permitted the warm air to be continually escaping. In addition, the oven was opened about every 3 days to make observations and add water to the evaporating pan. This would give a good aeration. The writers at first felt that the explanation might be that with certain low temperatures conditions result whereby not only katabolic activity or destructive metabolism but all metabolism is lessened or reduced to a minimum. On the other hand, with high temperatures and high relative humidity surrounding the fruit, conditions may be produced whereby the tissues are able, at least partially, to carry on anabolic activity or constructive metabolism, and hence

indirectly lessen the amount of rapidity of activity which would bring about deterioration.

As a result of further work, however, it seems probable that within a given limit high temperatures may act in the same manner as do the low temperatures to which fruits are subjected in cold storage; that is, temperatures approaching certain limits in either extreme cause a reduction in the protoplasmic and enzymatic activities of the fruit, and this, depending upon the extent of the inhibition, delays to a greater or less degree the attainment of ripeness. As has been stated elsewhere, the experiments reported upon are of a very preliminary nature, and an effort is being made to repeat them. Furthermore, at such high temperatures for any long period of time the flavor might be affected so that the quality would be appreciably lowered. As a matter of fact, the flavor of the pears subjected to the higher temperatures was somewhat abnormal. A slight acidity was noticeable and a lack of the normal sweetish taste and juiciness was apparent. This can probably be accounted for by the fact that the comparatively high temperatures would be expected to increase the respiration. Carbohydrates are necessary for respiration, and are gradually used by this process; hence it follows that the sugar content would have been decreased. This decreasing of the sugar content would have made the normal acid content somewhat more noticeable, and, in addition, it is possible that intramolecular respiration may have been carried on to a certain extent, and this give rise to waste products that affect the flavor.

A second drawback to the practicality of utilizing high temperatures and high humidity in keeping fruits is the danger from rot. Under such an environment, conditions are very favorable for the growth of fungi or bacterial organisms which would bring about the decay of the fruit. While the experiments, therefore, show that temperatures ranging from 95 to 110° F., with the optimum at about 104 or 105° F., will delay or prolong the normal ripening process of Bartlett pears at least two weeks, when contrasted with fruit placed at average room temperatures of 70 to 80° F., the danger from rot and the development of abnormal flavors limit the practical use of these higher temperatures.

Experiment 2

In the preceding experiment with the highest temperature used (104° F.) the Bartlett pears kept longest. The authors wished to ascertain whether temperatures higher than those employed in the first experiment would be more satisfactory. To determine this, and also to repeat in a measure the first experiment, a second experiment was conducted.

Observations on temperature and humidity

The method of procedure was just as outlined for the first experiment, except that the temperatures in the large drying oven were somewhat higher than was the case in experiment 1; that is, the top shelf (no. 1) had a temperature averaging 90° F. as contrasted with 85° F. in the first experiment; shelf no. 2 averaged 99.2° F. instead of 88° F.; shelf no. 3 averaged 109° F. instead of 94° F.; and shelf no. 4 averaged 121.2° F. as compared with 104° F. The Freas oven averaged about 101° F.; while in the first experiment it was kept at about 95° F. The other temperatures and the humidity were just about the same as for the first experiment.

The experiment was begun on September 25, 1918. One set consisted of 5 lb. grape baskets filled with first crop Bartlett pears; a second set consisted of second crop Bartletts; and the third set was filled with Easter pears. One lot of each set was placed under each of the varying conditions. By an improved arrangement for maintaining a high humidity, it was possible to fill the water pan from outside without opening the door of the oven. Since the writers knew just about what to expect from the large oven as well as the other compartments, and since the hygrothermographs were operated throughout this experiment as in the first one, it was not found necessary to open the door at frequent intervals to take readings. The hygrothermograph showed that the temperatures and humidity were quite uniform, in fact more so than in the first experiment because of better control, except on two occasions. The first was from noon, September 28, to noon, September 30. During this time the water pan was dry and the humidity dropped considerably below 50 per cent. At the same

time the temperature rose from 4 to 6° F. only above the temperatures indicated, as shown by the continuous record of the thermograph pen. The second was during the last 36 hours of the experiment, ending October 10, when the pan again went dry. The operation of the thermostat prevented any rise in temperature above the normal. In fact the thermostat was so closely adjusted that the variation in temperature at the hygrothermograph was only from 1 to 2° F. at any time except when the door was open.

The variation in humidity was somewhat greater on the bottom or fourth shelf, although it was probably close to 90±5 per cent. On the first three shelves the humidity was 100 per cent throughout the experiment, except during the times indicated. Room temperatures and humidity were practically the same as in the first experiment, not more than 1° F., or 6 per cent difference between the maxima and minima. The high humidity at room temperature was quite uniform, ranging from 94 to 100 per cent, average 96 per cent. The cold storage temperature and humidity were just the same as in the first experiment.

Behavior of fruit

The first crop Bartlett pears were near the end of their life period when first subjected to the experimental conditions. As a result, 3 or 4 days after the experiment was begun nearly all the specimens were physiologically broken down, as indicated by the blackening of the skin, and the browning and extreme softening of the tissue. No data of value, therefore, concerning the effects of high temperatures upon keeping quality, were obtained with this lot of nearly ripe Bartlett pears.

The second crop Bartlett and the Easter pears were green enough to show a response, with wide enough differences, depending upon the temperature, to be of interest in substantiating the first experiment, and to determine the effects of temperatures higher than those employed in the first test. The details of these are given in tables V and VI.

As indicated by the nearly ripe Bartlett pears, there is a point near the stage of complete maturity in ripening at which breakdown may rapidly come about, regardless of the environment.

TABLE V

CONDITION OF SECOND CROP BARTLETT PEARS DURING PROGRESS OF SECOND TEST, SEPTEMBER 25 TO OCTOBER 10, 1918

LOT NO.	TREATMENT	DATE OF EXAMINATION		
		September 28	October 3	October 10
1.....	High temperature (90° F.), high humidity (100 per cent)	Only slightly riper than when started	Firm, unripe, greenish yellow, extreme saturation developing mold on fruits	Firm, no wilting, nearly yellow, three-fourths colored, not yet ripe
2.....	High temperature (99.2° F.), high humidity (100 per cent)	Only slightly riper than when started	Firm, unripe, supersaturated atmosphere developing mold	Firm, no wilting, nearly yellow, not quite as ripe as lot 1
3.....	High temperature (109° F.), high humidity (91 per cent)	Only slightly riper than when started	Firm, unripe, greenish yellow; 1 fruit slight browning at stem end, others small brown rotten spots	Firm, no wilting, nearly yellow, not quite as ripe as lot 2; 3 fruits slight breakdown at base, lacking in flavor, quality very poor
4.....	High temperature (121.2° F.), moderate humidity (70 per cent)	Slight browning of skin to one-third breakdown	All chocolate colored throughout, cooked taste, quite firm	All gone
5.....	High temperature (101° F.), low humidity (well below 50 per cent)	Same as lot 3	Firm, unripe, greenish yellow, same as lot 3	Firm, wilted, not ripe, same as lot 1*
6.....	Room temperature (71° F.), room humidity (60 per cent)	About the same as lot 1	Full ripe, almost at best eating condition, light yellow, slightly wilted	Soft ripe, full clear yellow, at or slightly past best eating, no wilting
7.....	Room temperature (69° F.), high humidity (96 per cent)	Same as lot 6	Same as lot 6	Same as lot 6
8.....	Cold storage (32° F.), moderate humidity (70 per cent)	Same as when test started	Same as when test started	Practically same as when test started

*The second crop Bartlett pears of this lot was allowed to remain in the Freas oven until November 5 On this date, nearly 6 weeks after the experiment was started, the fruit could be described as five-sixths colored, unripe, dry, rather badly shriveled, and somewhat insipid, but not displeasing in flavor.

TABLE VI

CONDITION OF EASTER PEARS DURING THE PROGRESS OF THE SECOND TEST

LOT NO.	TREATMENT	DATE OF EXAMINATION		
		September 28	October 3	October 10
1.....	High temperature (90° F.), high humidity (100 per cent)	Green, same as when first put in, some mold developing	Green, firm, unripe; half of fruits largely or completely rotted with *Rhizopus* and *Penicillium* mold	Firm, unripe, lighter green than when put in
2.....	High temperature (99.2° F.), high humidity (100 per cent)	Green, same as when first put in, some mold	Green, firm, unripe; half of fruits largely or completely rotted with *Rhizopus* and *Penicillium* mold	Firm, unripe, greenish yellow; considerable mold
3.....	High temperature (109° F.), high humidity (91 per cent)	Green, same as when first put in, no mold	Green, firm, unripe; only slight mold at base of 2 fruits	Completely broken down, and rotted with mold, skin chocolate brown, flesh dirty white color
4.....	High temperature (121.2° F.), moderate humidity (70 per cent)	Green, same as when first put in, no mold	All fruits seemed cooked; skin chocolate colored with tissue soft and grayish white with flecks of brown scattered through, considerable internal breakdown	.....
5.....	High temperature (101° F.), low humidity (well below 50 per cent)	Green, same as when first put in, no mold	Same as lot 3, noticeably wilted	Unripe, light green with few small patches of yellowish green, very badly wilted

TABLE VI—*Continued*

Lot no.	Treatment	Date of examination		
		September 28	October 3	October 10
6.....	Room temperature (71° F.), room humidity (60 per cent)	Green, same as when first put in, no mold	Green, firm, unripe, very slightly wilted	Medium firm ripe, yellowish green, almost at best eating, somewhat wilted
7.....	Room temperature (69° F.), high humidity (96 per cent)	Green, same as when first put in, no mold	Same as lot 6, but even less wilted, practically plump	Firm ripe, light yellowish green, almost as ripe as lot 6
8.....	Cold storage (32° F.), moderate humidity (70 per cent)	Green, same as when first put in, no mold	Same as when put in	Same as when put in

This is true notwithstanding the fact that earlier in the period of ripening certain identical conditions, as contrasted with others, would appreciably arrest the ripening process.

The results of experiment 2 indicate that for Bartlett pears a nearly continuous temperature of 104–110° F., and a relative humidity of 95–98 per cent, result in the most marked delay of the ripening process when high temperatures are the factor employed. Temperatures above 110° F. result in a more rapid breakdown of the tissue than do any temperatures below. A temperature of 107° F. gives better results in delaying the ripening than 110° F. When the moisture content of the surrounding air is so high that water is precipitated on the fruit, the pears do not keep nearly as well as when the relative humidity is just sufficiently low to prevent this. This second experiment shows rather conclusively that within a certain limit high temperatures tend appreciably to delay the ripening of Bartlett and Easter pears. Excessively high humidity and these high temperatures, however, make conditions favorable for the infection and growth of fungi upon the pears. Low humidity and these high temperatures, of course, result in excessive wilting of the fruit.

Table V shows that the second crop Bartlett pears designated as lot 5 were of especial interest, in that they remained unripe for a relatively longer period than any of the other lots. Lot 5 was in the Freas oven at a temperature of 101° F. and surrounded by a relative humidity below 50 per cent until November 5. On this date, nearly 6 weeks after the beginning of the experiment, the pears were still unripe. When compared with fruits stored at room temperatures, this shows a delay in ripening of a little over 4 weeks. This lot also is of interest in that it indicates that it is a question of high temperature only, which causes the ripening processes to be inhibited, and that high relative humidity has no marked influence, except to lessen the amount of wilting.

The question arises why the fruit of lot 5 should keep longer than the fruit of lots 2 and 3, since the temperatures in each case were all comparatively high. The chief difference between these lots was the much lower relative humidity of lot 5, as contrasted with lots 2 and 3. It is probable that the greater desiccation or wilting of the pears of lot 5 did retard their ripening, but two other points should be mentioned. (1) When the relative humidity was high, much trouble was experienced from molds infecting the fruit and causing it to rot. There was no loss from rot in lot 5, due no doubt to the very low humidity. (2) The temperature of lot 3 was no doubt too high, and it is probable that the temperature surrounding lot 2 was somewhat below the optimum temperature for the retardation of the ripening.

Specimens from lot 5 were tested by Dr. J. RUDISCH and the senior author to determine if any enzymes were active. The tissue was treated with a tincture of guiac and gave no test for oxidase, either with or without the addition of hydrogen peroxide; neither could a test for an organic peroxide be shown upon the addition of a solution of potassium iodide, weak acid, and starch solution, as indicated by the liberation of free iodine and the consequent blueing of the starch solution. This might indicate that the higher temperatures had destroyed or inhibited the action of the ferments or enzymes normally present in the tissue of pears. This resulted in a checking of the ripening process with a consequent prolonging of the period in which the fruit could be kept.

Experiment 3

Effects of high temperatures upon keeping apples

Since Bartlett and Easter pears behaved in such an unexpected manner when subjected to temperatures of around 104° F., an endeavor was made to determine whether varieties of apples would behave in a similar manner. Yellow Newtown apples, which had previously been kept in cold storage at a temperature of 32° F., were subjected to high temperatures similar to the process in experiment 2.

The experiment was begun on December 12, with a 5 lb. grape basket filled with apples subjected to each of the several conditions. The temperatures varied as follows: 32, 70, 85, 95, 104, 110, and 120° F. The relative humidity was from 90 to 98 per cent in each case, except that the temperatures of 70° F. and 104° F. were duplicated, the relative humidity in one instance being somewhat below 50 per cent and in the other varying from 90 to 98 per cent. The results of this experiment can be summarized briefly. The ripening of the apples was not delayed by the higher temperatures. The rapidity of ripening was directly proportional to the temperature, in that with the degrees tried the higher the temperature the more rapid the ripening. After 2 weeks the fruit subjected to temperatures of 85° F. and above were all browned throughout and soft, tasting very much like baked apples. The fruit at 70° F., or room temperature, was yellow in color, ripe, and just about best for eating. The fruit at 32° F. was still green and hard unripe.

Practical applications

The practical applications of the data presented are somewhat limited, but the facts may be of value some years and in certain sections in connection with the time of picking Bartlett pears. For example, as a rule during the hottest seasons the growers have felt a greater necessity for earlier picking than when the season is normal at the time of ripening. In view of the results obtained, it may really happen that the ripening of the pears is delayed by the excessively hot weather, and would mean that the fruit might well be allowed to remain on the trees longer than would be the

case in a normal season. This would be of especial value when fruit was being harvested and packed for eastern shipment. Pears are picked comparatively early in order to reach distant markets in good condition. While they should preferably not be allowed to ripen on the tree, to avoid the marked development of the grit cells, it might mean that in excessively hot years, contrary to expectations, the fruit could be left somewhat longer on the trees, and thereby develop a better flavor and quality. If all varieties of apples behave as do Yellow Newtown, high temperatures do not delay ripening. Instead, up to the point of tissue destruction by heat, the higher the temperature, the more rapid the ripening. This emphasizes the necessity of hurrying into low temperatures apples which are to be stored for any length of time.

Summary

1. When contrasted with temperatures between 70 and 85° F., temperatures of 87.7 to 110° F. caused an appreciable delay in the ripening of green first crop Bartlett pears.

2. The retardation of ripening was directly proportional to the increased degree of heat within the limits of 87 and 104° F.

3. The amount of delay in ripening of green first crop Bartlett pears of the different temperatures when contrasted with 70° F., or room temperature, was as follows: 85° F., no retardation; 87.7°, 5 days; 94° F. and 104° F., 13 days.

4. Second crop Bartlett pears, placed at a temperature of 101° F. and surrounded by a relative humidity of below 50 per cent, remained unripe 4 weeks after similar pears had become fully ripe at room temperature and humidity.

5. The relative humidity does not seem to be a significant factor in checking the ripening processes. Its effect is in lessening or permitting wilting, depending upon whether the relative humidity surrounding the fruit is high or low.

6. The flavor of the pears subjected to those temperatures higher than 85° F. was not normal. There was a slight acidity, and the sweetish taste and juiciness were lacking.

7. Temperatures above 110° F. result in a more rapid ripening and consequent breakdown of the tissue than do any of the lower temperatures, down to average room temperatures.

8. As would be expected, there was a comparatively large loss from rot with the fruit kept at high temperatures and surrounded by high relative humidity.

9. A possible explanation of the effects of high temperatures may lie in the influence upon the enzymes. Temperatures approaching the probable minimum (around 28° F.) on the one hand, and the probable maximum (around 110° F.) on the other, might result in a reduction of enzymatic activities of the fruit and a consequent retardation of the ripening processes; while with the optimum temperatures (70–85° F.) the enzymatic activity would be most marked, and hence the ripening most rapid.

10. If the Bartlett pears have nearly reached a stage of complete ripeness, the temperatures above 70° F. do not check the ripening process. On the other hand, the ripening and breakdown are more rapid with each appreciable rise in temperature.

11. Unripe Easter pears behave in a manner comparable to the Bartlett when placed under similar conditions of high temperatures and relative humidity.

12. The process of ripening with Yellow Newtown apples is not delayed by temperatures above 32° F. The ripening takes place with increased rapidity with each appreciable rise in temperature above 32° F. This is true with temperatures up to a point which result in the disorganization of the protoplasmic contents of the cells.

13. The experiments suggest that with an excessively hot season during the time of ripening, Bartlett and Easter and possibly other pears might be allowed to remain on the trees somewhat longer than with a normal season.

14. For Yellow Newtown and no doubt other varieties of apples, which are to be stored any length of time, the necessity of quickly cooling after harvesting is emphasized.

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